

EVALUATION OF PALM OIL MILL EFFLUENT (POME) BY  
MEMBRANE ANEROBIC SYSTEM (MAS)

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## ABSTRACT

The evaluation of anaerobic digestion process of palm oil mill effluent (POME) was carried out in a laboratory-scale membrane anaerobic system (MAS). The MAS consists of a cross-flow Ultra-filtration membrane for solid-liquid separation and operational pressure of 1.5 to 2 bars. An enrichment mixed culture of methanogenic bacteria was developed and acclimatized in the digester for three days when the POME is fed into the 30 L digester combining Ultrafiltration (UF) membrane MAS is a modern bioreactor and was used for the rapid biotransformation of organic matter to Methane gas with the help of Methanogenic bacteria. Two concentration ratios of 50% and 100% of the raw POME were studied. The hydraulic retention time (HRT) ranged between 1 and 4 days. Throughout the experiment, the removal efficiency of COD was between 78.81% and 81.44%. The methane gas production rate was 0.673 L/g COD/d to 0.974 L/g COD/d. The effluent flow rates for the two ratios were found as 10.31 L/d and 21.75 L/d respectively. The pH was between 6.8 and 7.7. The membrane anaerobic system, MAS treatment efficiency was greatly affected by solid retention time, hydraulic retention time and organic loading rates. In this study, membrane fouling and polarization at the membrane surface played a significant role in the formation of the strongly attached cake layer limiting membrane permeability.

## ABSTRAK

Evaluasi proses pencernaan anaerobik sisa kilang kelapa sawit (POME) dilakukan dalam skala makmal membran sistem anaerob (MAS). MAS terdiri daripada Ultra-penapisan membran untuk pemisahan pepejal-cecair dan tekanan operasi 1.5 hingga 2 bar. Kultur campuran bakteria metanogen dibangunkan dan dibiarkan menyesuaikan diri dalam Digester selama tiga hari untuk menyesuaikan diri dengan persekitaran POME dimasukkan ke dalam Digester 30 L menggabungkan Ultrafiltrasi (UF) membran Bioreaktor moden dan digunakan untuk merawat bahan organik dan menukarkan kepada metana dengan bantuan bakteria metanogen. Sample POME yang mempunyai dua jenis kepekatan yang berlainan telah dikaji iaitu kepekatan sebanyak 50% dan 100%. Masa penahanan hyroulik (HRT) berkisar antara 1 dan 4 hari. Sepanjang percubaan, kecekapan penyisihan COD adalah antara 78.81% dan 81.44%. Tingkat pengeluaran gas metana adalah 0,673 L / g COD / hari untuk 0,974 L COD / g / hari. Aliran sisa cecair untuk kedua-dua kepekatan dijumpai sebagai 10.31 L / hari dan 21.75 L / hari. pH adalah antara 6.8-7.7. Sistem anaerobik membran, MAS kecekapan perubatan sangat dipengaruhi oleh masa penahanan hyroulik pepejal, masa penahanan hyroulik dan tahap beban organik. Dalam kajian ini kerosakan membran dan polarisasi pada permukaan membran memainkan peranan penting dalam pembentukan lapisan pejal yang mempengaruhi ketelapan membran.

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**LIST OF SYMBOLS / ABBREVIATIONS**

BOD	Biological Oxygen Demand ( $\text{mg L}^{-1}$ )
COD	Chemical Oxygen Demand ( $\text{mg L}^{-1}$ )
$\text{CO}_2$	Carbon Dioxide
CUF	Cross flow Ultra filtration Membrane
$\text{CH}_4$	Methane gas
DOE	Department of Environment
EFB	Empty Fruit Bunches
ETP	Effluent Treatment Bunches
FFB	Fresh Fruit Bunch
HRT	Hydraulic Retention Time (day)
$\text{H}_2$	Hydrogen gas
MAS	Membrane Anaerobic System
MRE	Mixed Row Effluent
MWCO	Molecular Weight Cut Off
NaOH	Sodium Hydroxide
$\text{NH}_3$	Ammonia gas
POME	Palm Oil Mill Effluent
SS	Suspended Solids
TSS	Total Suspended Solid ( $\text{mg L}^{-1}$ )
UF	Ultra-Filtration membrane

## CHAPTER 1

### INTRODUCTION

#### 1.1 Background of research.

Malaysia is a major producer of palm oil in the world. The production of crude palm oil reached 17.73 million tonnes in the year 2008, increases to 19.64million tonnes in year 2009 (MPOB, 2009). This amount will continuously increase in proportion to the world demand of edible oils seeing as palm oil already is bio-diesel product. Although the palm oil industry is the major revenue earner for our country but it has also been identified as the single largest source of water pollution source due to the palm oil mill effluent (POME) characteristic with high organic content and acidic nature.

In palm oil mills, liquid effluent is mainly generated from sterilization and clarification processes in which large amounts of steam and hot water are used (zinatizadeh *et al.*, 2006). For every ton of palm oil fresh fruit bunch, it was estimated that 0.5-0.75 tones of POME will be discharged (Yacob *et al.*,2006) . In general appearance, palm oil mill effluent (POME) is a yellowish acidic wastewater with fairly high polluting properties, with average of 25,000 mg/L biochemical oxygen demand (BOD), 55250 mg/L chemical oxygen demand (COD) and 19610mg/L suspended solid (SS). This highly polluting wastewater can cause several pollution problems and also create odor problems to the neighborhoods of the mills such as a nuisance to the passers- by or local residents and river pollution. Thus, there is need to prevent environmental pollution due to the increase of crude palm oil production.

Over the past 20 years, the technique available for the treatment of POME in Malaysia has been basically biological treatment, consisting of anaerobic, facultative and aerobic pond systems (Chooi, 1984; Ma, 1999). The pond system has been applied in our country for POME treatment since 1982 (Ashhuby *et al.*, 1996). Most of the pond system that has been applied for the treatment of POME in Malaysia was classified as waste stabilization pond. The configuration of this system consists of essentially a number of ponds of different functions such as anaerobic, facultative and aerobic ponds. Thus, anaerobic ponds are one of the most effective treatments that are being applied in Malaysia either in pond system or close digesting tank systems to treat highly concentrated POME wastewater. This is because the anaerobic process has considerable advantages such as (a) it demands less energy, (b) sludge formation is minimal, (c) unpleasant odors are avoided, and (d) anaerobic bacteria efficiently break down the organic substances to methane (Rincon *et al.*, 2006).

Anaerobic digestion is the breakdown of organic material by micro-organisms in the absence of oxygen. Although this takes place naturally within a landfill, the term normally describes an artificially accelerated operation in closed vessels, resulting in a relatively stable solid residue. Biogas is generated during anaerobic digestion which mostly methane and carbon dioxide and this gas can be used as a chemical feedstock or as a fuel. The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Methanogens finally are able to convert these products to methane and carbon dioxide.

Throughout this research, a membrane anaerobic system (MAS) at steady state was operated continuously at different hydraulic retention time (HRT) and waste concentration in order to evaluate the performance of the reactor in term of biogas production.

## **1.2 Problems statement.**

As mentioned earlier, large quantities of POME wastewater are produced from the crude palm oil extraction process. This large amount of wastewater if discharged untreated into freshwater, estuarine and marine ecosystems may alter aquatic habitats, affect aquatic life and adversely impact human health. However, the treatment of wastewater is always a burden and costly for many industrialists. Therefore, a new and effective approach in wastewater treatment technology should be developed to comply with stringent environmental regulations on the quality of the effluent entering receiving waters.

In relation to that, several POME wastewater treatment plants have been successfully operated but majority of the plants are still struggling to observe the Malaysian discharge standards under Environmental Quality Act (EQA 1974) (Prescribed Premises) (Crude Palm Oil) Regulations in 1977. Most of the palm oil mill industries are facing a common problem; an under designed wastewater plant to cope with ever growing production. Though installation of higher capacity plant and new alternative treatment system such as membrane technology will be an alternative but it always involves a high cost. In practice, it has been observed that all industries prefer simple, low cost wastewater treatment technology.

Throughout this research study, the studies would be focused on the Anaerobic digestion is considered to be an effective treatment process for (POME). This involves a consortium of microorganisms catalyzing a complex series of biochemical reactions that mineralize organic matter producing methane and carbon dioxide. The key factors to successfully control the stability and efficiency of the process are reactor configurations, hydraulic retention time (HRT), waste concentration, pH, and temperature. In order to avoid a process failure and low efficiency, these parameters require an investigation so that they can be maintained at or near to optimum conditions.

Generally, these anaerobic digestions are conducted at either mesophilic (30°C - 37°C) or thermophilic (50°C - 60°C) temperatures. In a palm oil mill processing system, the wastewater is discharged at relatively high temperatures (70°C - 90°C) (Najafpour *et al.* 2006), making it feasible to treat the POME at either mesophilic or thermophilic temperatures. Therefore, this research study is required to investigate the efficiency of MAS to treat POME.

### **1.3 Objectives of the study**

This research aims to examine the performance of POME wastewater in the anaerobic reactor which works under room temperature. The specific objectives are:

- To evaluate the efficiency of Membrane Anaerobic System in term of Methane gas production.
- To experimentally assess the influence of waste concentration and retention times on the parameters (COD, TSS, Turbidity, Manganese and Iron).

### **1.4 Scope of the research**

The treatment of POME wastewater is in demand due to the pollution problems created from the high volume of wastewater generated by the palm oil mill industry. The anaerobic digestion process is the main focus in this study. To accomplish these objectives, a laboratory scaled membrane anaerobic system (MAS) with an effective 20 liter volume used to treat Palm Oil Mill Effluent (POME). The laboratory digester is completely semi-continuous process followed steady state operation. There also some limitations of these studies to ensure all results are base on parameters. The limitations are:

- Using optimum temperature for anaerobic digestion in the mesophilic range at 25°C-45°C
- The pH of the reactor content maintain at 6.8-7.7
- Using 0.5 M NaOH as a solvent to absorb the carbon dioxide, CO<sub>2</sub>
- The operating pressure is maintain at 1.5-2.0 bar
- Using two different waste concentration (50% and 100%) and Hydraulic retention times (HRT) is 4 days
- Volume of Methane gas was measure daily, using J-Tube analyzer.
- The COD, TSS, Turbidity, Manganese, Iron and pH of feed's and permeate are measure every day.

### **1.5 Rationale and significant.**

Rationally, this research can help to develop another environmental friendly alternative to overcome the emission of green houses gases such as methane and carbon dioxide to the atmosphere. This is because anaerobic digestion produces biogas from biodegradable waste that can be burnt to generate heat or electricity or also can be used as a vehicle fuel.

Anaerobic digestion technology serves dual-function that is as wastewater treatment and energy generation (organic conversion to methane gas). This technique offer fundamental benefits such as low costs, energy production, and relatively small space requirement of modern wastewater treatment systems.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Palm Oil Industry in Malaysia**

##### **2.1.1 History and Development of Palm Oil Industry**

The oil palm tree (*Elaeis guineensis*) originated from West Africa where it was grown wild and later developed into an agriculture crop. It was first introduced to Malaysia in the early 1870's as an ornamental plant. In the year 1917, the first commercial planting took place at Tennamaran Estate in Selangor, laying the foundation for the vast oil palm plantations and palm oil industry in Malaysia. Today, 3.88 million hectares of land in Malaysia is under oil palm cultivation producing 14 million tonnes of palm oil in 2004. Malaysia is the largest producer and exporter of palm oil in the world, accounting for 30% of the world's traded edible oils & fats supply. (MPOC, 2009).

Oil palm is a crop that bears both male and female flower on the same tree, meaning they are monoecious. Each tree produces compact bunches weighing between 10 and 25 kilograms with 1000 to 3000 fruitlet per bunch. Each fruitlet is almost spherical or elongated in shape. Generally the fruitlet is dark purple, almost black and the colour turns to orange red when ripe. Each fruitlet consists of hard kernel (seed) inside a shell (endocarp) which is surrounded by the fleshy mesocarp. Palm trees may grow up to sixty feet and more in height. The trunks of young and adult plants are wrapped in fronds which give them a rather rough appearance. The



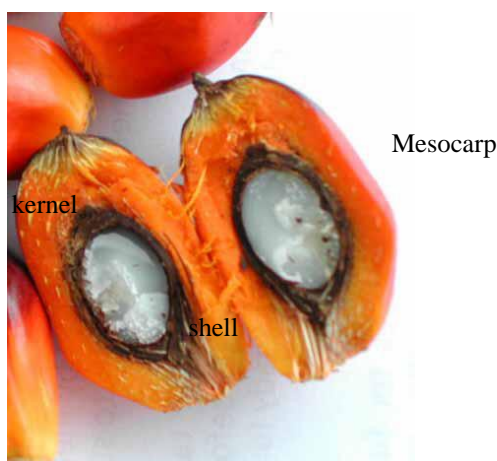
older trees have smoother trunks apart from the scars left by the fronds which have withered and fall on off.

A normal oil palm tree will start bearing fruits after 30 months of planting and will continue to be productive for the next 20 to 30 years thus ensuring a consistent supply of oil. Each ripe bunch is commonly known as Fresh Fruit Bunch (FFB). In Malaysia, the trees planted are mainly the *tenera* variety, a hybrid between the *dura* and *pisifera*. The *tenera* variety yields about 4 to 5 tonnes of crude palm oil (CPO) per hectare per year and about 1 tonne of palm kernels. The oil palm is most efficient, requiring only 0.25 hectares to produce one tonne of oil while soybean, sunflower and rapeseed need 2.15, 1.50 and 0.75 hectares respectively (MPOC,2009).



**Figure 2.1** Empty Fruit Bunches (FFB)

[www.flickr.com/photos/9496861@N02/1840425900](http://www.flickr.com/photos/9496861@N02/1840425900)



**Figure 2.2** cross section of fruitlet

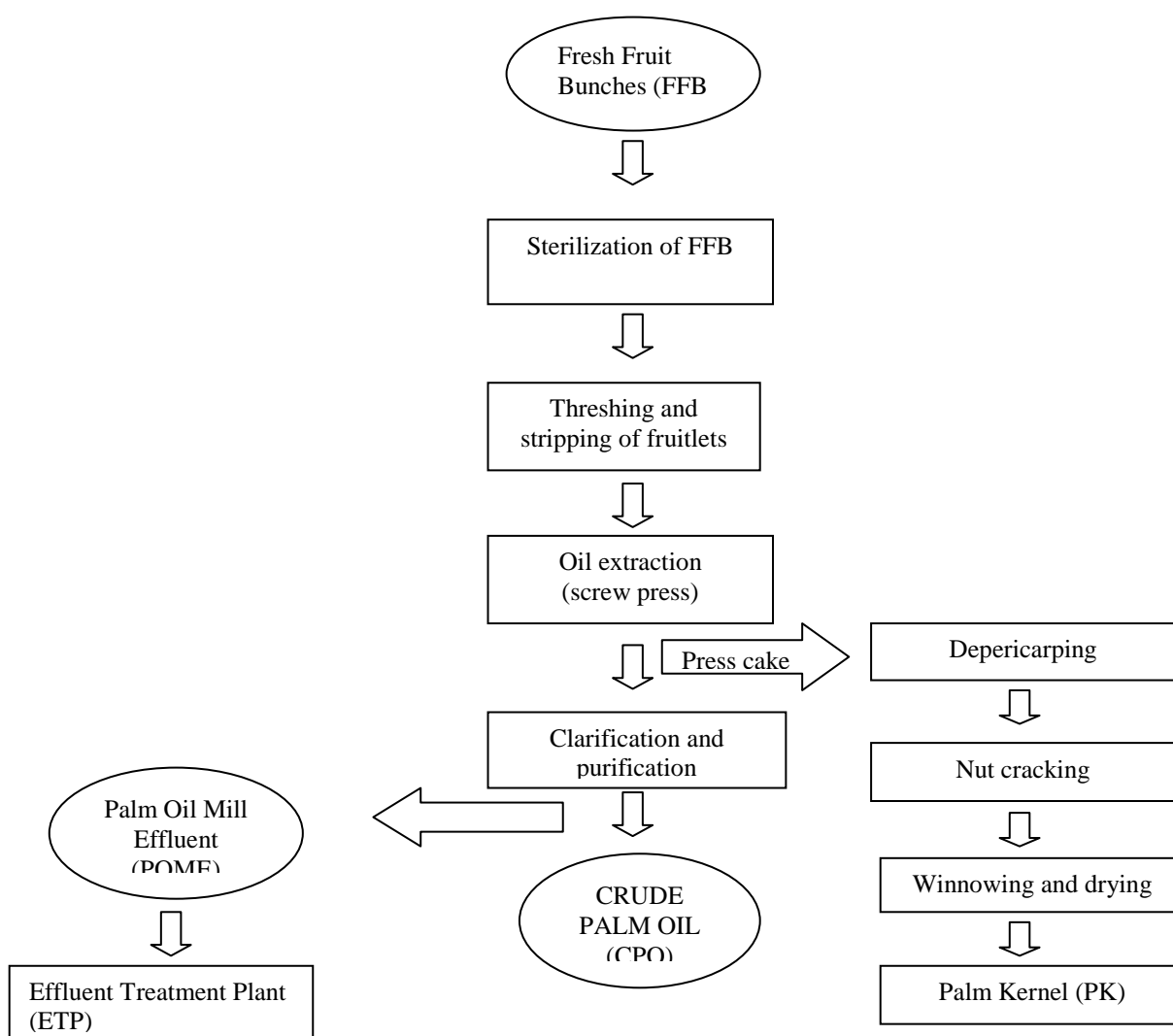
<http://www.oilsvegetable.com/palmoil.htm>

### **2.1.2 Palm Oil Mill Process**

Palm Oil Milling Process involve the physical extraction of palm products namely, crude palm oil and palm kernel from the FFB. The process begin with sterilization of FFB. The fruit bunches are steamed in pressurized vessel up to 3 bars to arrest the formation of free fatty acids and prepare the fruits for subsequent sub-processes. The sterilized bunches are then stripped of the fruitlets in a rotating drum thresher. The stripped bunches or empty fruit bunches (EFB) are transported to the plantation for mulching while the fruitlets are conveyed to the press digesters.

In the digesters, the fruits are heated using live steam and continuously to loosen the oil-dearing mesocarp from the nuts as well as to break open the oil cells present in the mesocarp. The digested mash is then pressed, extracting the oil by means of screw presses. The press cake is then conveyed to the kernel plant where the kernels are recovered. The oil from the press is diluted and pumped to vertical clarifier tanks. The clarified oil is then fed to purifiers to remove dirt and moisture before being dried further in the vacuum drier. The clean and dry oil is ready for storage and dispatch.

The sludge from the clarifier sediment is fed into bowl centrifuges for further oil recovery. The recovered oil recycled to the clarifiers while the water or sludge mixture which is referred to as Palm Oil Mill Effluent (POME) is treated in the effluent treatment plant (ETP). The press cake is conveyed to the depericarper where the fiber and nuts separated. Fiber is burned as fuel in the boiler to generate steam.



**Figure 2.3** Palm Oil Milling Process

Source : T.Cheng(2002)

### 2.1.3 Palm Oil Mill Effluent (POME)

Based on the process of oil extraction and the properties of FFB, POME is made up of about 95% - 96% water, 0.6% - 0.7% oil, and 4% - 5% total solid, including 2% - 4% suspended solids, which are mainly debris from mesocarp. No chemical are added during the production of palm oil; thus it is nontoxic waste. Upon discharge from the mill, POME is in the form of highly concentrated dark brown colloidal slurry of water, oil, and fine cellulosic materials. Due to introduction of heat (from the sterilization stage) and vigorous mechanical processes, the discharge temperature of POME is approximately 80°C - 90°C. The chemical properties of POME vary widely and depend on the operation and quality control of individual mills. The general properties of POME are indicated in Table 2 (Lawrence *et al*).

Apart from the organic composition, POME is also rich in mineral content, particularly Phosphorus (18mg/L), Potassium (2270mg/L), Magnesium (615mg/L) and Calcium (439 mg/L). Thus most of dewatered POME dried sludge (the solid end product of the POME treatment system) can be recycled or returned to the plantation as fertilizer (Lawrence *et al*).

**Table 2.1** Chemical Properties of Palm Oil Effluent (POME)

<b>Chemical property</b>	<b>Average</b>	<b>Range</b>
<b>Ph</b>	4.2	3.4-5.2
<b>BOD (mg/L)</b>	25000	10250-43750
<b>COD (mg/L)</b>	50000	15000-100000
<b>Oil and grease (mg/L)</b>	6000	150-18000
<b>Ammonia (mg/L)</b>	35	4-80
<b>Total nitrogen (mg/L)</b>	750	180-1400
<b>Suspended solid (mg/L)</b>	18000	5000-54000
<b>Total solid (mg/L)</b>	40000	11500-78000

Source : Lawrence *et al*

## 2.2 Palm Oil Mill Effluent Wastewater Treatment

The choice of POME wastewater treatment system is largely influenced by cost of operation and maintenance, availability of land, and location of the mill. The first factor plays a bigger role in the selection of the treatment system. In Malaysia, the final discharge of the treated POME must follow the standards set by the Department of Environment (DOE) of Malaysia, which is 100 mg/L of BOD or less (Table 2.3) regardless of which treatment system is being utilized.

**Table 2.2:** Environment Regulation for watercourse  
Discharge for Palm Oil Mill Effluent (POME)

Parameters	Level
<b>BOD (mg/L)</b>	100
<b>Suspended Solid (mg/L)</b>	400
<b>Oil and Grease (mg/L)</b>	50
<b>Ammonia cal Nitrogen(mg/L)</b>	150
<b>Total Nitrogen (mg/L)</b>	200
<b>Ph</b>	5-9

Source: Industrial process and the environment (Handbook No.3)

### 2.2.1 Pretreatment

Prior to the primary treatment, the mixed raw effluent (MRE), a mixture of wastewater from sterilization, clarification, and other sources) will undergo a pretreatment process that includes the removal of oil and grease, followed by a stabilization process. The excess oil and grease is extracted from the oil recovery pit using an oil skimmer. In this process, steam is continuously supplied to the MRE to aid the separation between oil and liquid sludge. The recovered oil is then reintroduced to the purification stage. The process will prevent excessive scum formation during the primary treatment and increase oil production. The MRE is then pumped into the cooling and mixing ponds for stabilization before primary treatment. No biological treatment occurs in these ponds. However, sedimentation of abrasive particle such as sand ensures that all pumping equipment is protected. The retention time of MRE in the cooling and mixing ponds is between 1 and 2 days (Lawrence *et al*)

### 2.2.2 Pond Treatment System

The pond system is comprised of a series of anaerobic, facultative, and algae (aerobic) ponds. These systems require less energy due to the absence of mechanical mixing, operation control, or monitoring. Mixing is very limited and achieved through the bubbling of gases; generally this is confined to anaerobic ponds and partly facultative ponds. On the other hand, the ponding system requires a vast area to accommodate a series of ponds in order to achieve the desired characteristics for discharge. For example, in the Seriting Hilir Palm Oil Mill, the total length of the wastewater treatment system is about 2 Km, with each pond about the size of a soccer field (Figure 2.3). Only a clay lining of the ponds is needed, and they are constructed by excavating the earth. Hence, the pond system is widely favored by the palm oil industry due to its marginal cost.

In constructing the ponds, the depth is crucial for determining the type of biological process. The length and width differ based on the availability of land. 1m - 1.5m deep. For anaerobic ponds, the optimum depth ranges from 5m - 7m, while facultative anaerobic ponds are 1m - 1.5m deep. The effective hydraulic time (HRT) of anaerobic and facultative anaerobic systems is 45 and 20 days, respectively. A shallower depth of approximately 0.5m - 1m is required for aerobic ponds, with an HRT of 14 days. The POME is pumped at a very low rate of 0.2Kg to 0.35Kg BOD/m<sup>3</sup> . day of organic loading. In between the different stages of the pond system, no pumping is required, as the treated POME will flow using gravity or a sideways tee-type subsurface draw-off system. Under these optimum conditions, the system is able to meet the requirement of DOE. The number of ponds will depends on the production capacity of each palm oil mill.

One problem faced by pond operators is the formation of scum, which occurs as the bubbles rise to the surface, taking with them fine suspended solids. This results from the presence of oil and grease in the POME, which are not effectively removed during the pretreatment stage. Another disadvantage of the pond system is the accumulation of solid sludge at the bottom of the ponds. Eventually the sludge and scum will clump together inside the pond, lowering the effectiveness of the pond by

reducing the volumetric capacity and HRT. When this happens, the sludge may be removed by either using submersible pumps or excavators. The removed sludge is dewatered and dried before being used as fertilizer. The cleanup is normally carried out every 5 years or when the capacity of the pond is significantly reduced.



**Figure 2.4** A series of ponds for POME treatment occupying a large land area. (courtesy of Felda Palm industries).

### 2.2.3 Facultative Ponds

Facultative ponds are generally aerobic; however these ponds do operate in facultative manner and have an anaerobic zone. Facultative organisms function with or without dissolved oxygen. Treatment in a facultative pond is provided by settling of solids and reduction of organic oxygen demanding material by bacteria activity. Dissolved oxygen is supplied by algae living within the pond and atmospheric transfer through wind action. Facultative ponds are usually 4-8 feet in depth and can be viewed as having three layers. The top six to eighteen inches is aerobic where aerobic bacteria and algae exist in a symbiotic relationship. Aerobic stabilization of BOD by aerobic bacteria occurs in the upper oxygenated layer. The aerobic layer is important in maintaining an oxidizing environment in which gases and other compound leaving the lower anaerobic layer are oxidized.



The middle two to four feet is partly aerobic and partly anaerobic, in which facultative bacteria decompose organic material. The bottom one to two feet is where accumulated solids are decomposed by anaerobic bacteria. BOD can be converted to methane by methane bacteria in the lower anaerobic layer. Maintaining a balance between the depth and surface area is important for facultative ponds to function properly. Aerobic reactions in facultative ponds are limited because they do not have mechanical aeration. Facultative and anaerobic reactions need more time than aerobic reactions to provide the same degree of treatment (Lagoon system in Maine). The disadvantage of this system is the requirement of a relatively large land area (Lim *et al.*,2006)



**Figure 2.5** Facultative pond of Sewage Treatment Plant

Source : Indah Water Kuatan

#### **2.2.4 Anaerobic Ponds**

Anaerobic ponds are deep treatment ponds that exclude oxygen and encourage the growth of bacteria, which break down the effluent (figure 2.5). It is in the anaerobic pond that the effluent begins breaking down in the absence of oxygen. The anaerobic pond acts like an uncovered septic tank. Anaerobic bacteria break down the organic matter in the effluent, releasing methane and carbon dioxide. Sludge is deposited on the bottom and a crust forms on the surface. Anaerobic ponds commonly 2m - 5m deep and receive such a high organic loading (usually 100g

BOD/m<sup>3</sup> d equivalent to 3000 Kg/ha/d for depth of 3 m). They contain an organic loading that is very high relative to the amount of oxygen entering the pond, which maintains anaerobic conditions to the pond surface. Anaerobic ponds do not contain algae, although occasionally a thin film of mainly *Chlamydomonas* can be seen at the surface.

Anaerobic ponds reduce Nitrogen, Phosphorus, Potassium and pathogenic microorganisms by sludge formation and the release of ammonia into the air. As a complete process, the anaerobic ponds serve to:

- Separate out solid from dissolved material as solids settle as bottom sludge
- Dissolve further organic material
- Break down biodegradable organic material
- Store undigested material and non-degradable solids as bottom sludge
- Allow partially treated effluent to pass out

This is a very cost effective method of reducing BOD. Normally, a single anaerobic pond in each treatment train is sufficient if the strength of the influent wastewater is less than 1000 mg/L BOD (McGarry and Pescod, 1970).